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Systems Design Approach to Precision Strike

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THE PROBLEM WITH ACQUIRING AND DESTROYING SCUD LAUNCHERS DURING DESERT STORM PROVIDED A MEANS FOR CADETS TO APPLY THE SYSTEMS DESIGN PROCESS LEARNED IN SE 401 TO A REAL WORLD PROBLEM. THE SYSTEMS DESIGN PROCESS IS TWO-STAGED WITH A FEASIBILITY STUDY AND THE PRELIMINARY DESIGN. THE FEASIBILITY STUDY INCLUDES THE NEEDS ANALYSIS, PROBLEM DEFINITION, SYNTHESIS OF SOLUTIONS, AND FEASIBILITY SCREENING. THE RESULT OF THE FEASIBILITY STUDY IS A LIST OF FEASIBLE ALTERNATIVES THAT MEET THE CLIENT'S NEEDS. THE PRELIMINARY DESIGN INCLUDES MODELING OF THE CRITERIA, SELECTION OF ALTERNATIVES, SENSITIVITY ANALYSIS, COMPATIBILITY ANALYSIS, OPTIMIZATION OF PARAMETERS, AND PREDICTION OF PERFORMANCE. THE RESULT OF THE PRELIMINARY DESIGN IS THE "BEST" ALTERNATIVE TO MEET THE CLIENT'S NEEDS.

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Systems Design Approach to Precision Strike

LTC David W. Hutchison
MAJ Jerry V. Wright

A TECHNICAL REPORT
OF THE
OPERATIONS RESEARCH CENTER
UNITED STATES MILITARY ACADEMY

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Department of Systems Engineering

15 June 1993

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Vitae

Lieutenant Colonel David W. Hutchison was born in Waterloo, Iowa in 1954. He graduated from the United States Military Academy in 1976 and received a commission as a Second Lieutenant in the Infantry. LTC Hutchison served in a variety of military assignments in Colorado, Georgia, and Italy. In 1983, he completed graduate school and received his Master of Science in Applied Math from the Massachusetts Institute of Technology. In 1992, LTC Hutchison began an assignment as an instructor on the faculty at the United States Military Academy. LTC Hutchison spent his first year on the faculty teaching courses in systems design. LTC Hutchison is currently the Group Manager for the Systems Design Group in the Department of Systems Engineering.

Major Jerry V. Wright was born in Wichita Falls, Texas in 1959. He graduated from the United States Military Academy in 1981 and received a commission as a Second Lieutenant in the Field Artillery. MAJ Wright served in a variety of military assignments in Oklahoma, California, and the Federal Republic of Germany until 1989. In 1991, he completed graduate school and received his Master of Science in Operations Research from the Naval Postgraduate School prior to beginning an assignment as an instructor on the faculty at the United States Military Academy. MAJ Wright spent his first year on the faculty teaching courses in systems design. For the past year, MAJ Wright was the course director for the final design course in the Systems Engineering sequence.

Acknowledgments

This course and this problem began with the efforts of MAJ Joseph Stallings and his association with the Directorate of Combat Developments for the Field Artillery School at Fort Sill, Oklahoma. This particular report was developed in response to the association with COL John Fricas, Director, Joint Precision Strike Demonstration Task Force. COL Fricas' work with the problem provided the basis for this report.

Table of Contents

Executive Summary

The problems with acquiring and destroying Scud launchers during Desert Storm provided a means for cadets to apply the systems design process learned in SE401 to a real world problem. The Systems Design process is two-staged with a Feasibility Study and the Preliminary Design. The Feasibility Study includes the Needs Analysis, Problem Definition, Synthesis of Solutions, and Feasibility Screening. The result of the Feasibility Study is a list of feasible alternatives that meet the client's needs. The Preliminary Design includes Modeling of the Criteria, Selection of Alternatives, Sensitivity Analysis, Compatibility Analysis, Optimization of Parameters, and Prediction of Performance. The result of the Preliminary Design is the "best" alternative to meet the client's needs.

The operational/primitive need given to cadets was:

> It is perceived that a system is required to destroy the Mobile Scud Missile Launchers. The system, if warranted, must be fielded by August of 1995. Time and funding dictate that improvements to current systems or developmental systems may be pursued but new system concepts will not be considered for this interim solution. A separate directive will authorize development of new concepts for a long term solution. This interim design directive authorizes the design of a system which utilizes the following combat systems as required.

Using only research material from public sources and unclassified artificial data provided, the cadets took the operational need and performed a needs analysis and defined the problem. They were given the following resources for their problem:

JSTARS	Joint Surveillance Target Attack Radar System
GUARDRAIL Common Sensor	(An Emitter Sensor System)
National Resources	(Satellite Reconnaissance)
UAV	Unmanned Aerial Vehicles
GSM	Ground Station Module
MCS/CTT	Maneuver Control System/Commanders Tactical Terminal
ASAS	All Sources Analysis System
TACFIRE/AFATDS	Field Artillery Tactical Fire Direction System/Advanced Field Artillery Tactical Data System
M270 MLRS	Corps Deep Fire Delivery System
MLRS Family of Munitions	

Conducting a functional breakdown of each resource into subsystems enabled the cadets to use Zwicky's Morphological Box and synthesize many different alternative combinations. Each cadet design group then screened each subsystem against user, physical, legal, social, economic, and financial constraints. The constraints were either given to the cadets in the form of additional information, or developed from the research material. The result was a list of feasible alternatives to be forwarded into the Preliminary Design.

To make the problem manageable, eight candidate alternatives were provided to the cadets in which they selected four to conduct the Preliminary Design. To keep the cadets focused in the right direction and for teaching purposes, seven criteria were provided. They were:

1. Time to identify and engage the target.
2. Probability of finding 1 Scud operating in the Corps AOI within 10 hours.
3. Range of the munition.
4. Probability of killing the Scud launcher given a detection has occurred.
5. Expected utilization of the munition.
6. Cost to search for 10 hours.
7. Cost per attack.

The cadet design groups modeled the criteria, applied the models and Multi-Attribute Utility Theory to their alternatives, and rank ordered their candidate systems. The spreadsheet Quattro Pro was used as the software package to conduct these steps. The cadets then applied sensitivity analysis to gain some confidence in their top selection.

Cadet design teams then conducted compatibility analysis on various parameters to identify the bounds of the parameters within the constraints of the system. The cadets were given a list of ten parameters in which they chose four to conduct the compatibility analysis. The ten parameters provided were:

1. Size of AOI (AOI)
2. Warhead Weight (WW)
3. Fuel Cost (FUELCOST)
4. Number of Scuds in the AOI (NSCUD)
5. Number of shooters in the AOI (NSHTR)
6. Cost of Current Motor
7. Cost of Extended Range Motor
8. Cost of Guidance System
9. Cost of Single APAM
10. Cost of one pound of HE

The cadets took the three parameters that caused the greatest change in the overall utility score (utility was used as a surrogate for overall systems performance) for the alternative and conducted an optimization on those parameters. The software package Quattro Pro was again used to optimize the overall utility score of the candidate system using the parameters as the variables.

Finally, a different scenario was provided to the cadets to predict how their system might perform in a completely different part of the world. A comparison between the original system, the optimized, system, and the predicted system was conducted. The scenario provided follows:

> The X Corps has been deployed to South Korea to defend in sector along the North Korean/South Korean Border. The Corps has one Scud Find and Destroy System (which includes the appropriate acquisition system(s), one GSM, access to the ASAS, and one dedicated MLRS launcher with appropriate missile) attached. The Corps has been assigned a sector 200 kilometers wide. The Corps area of interest extends 300 kilometers deep into North Korean territory. Operational data on fuel consumption rates for this environment indicate that less fuel is used in North Eastern Asia (NEA) then in South West Asia (SWA). Fuel consumption rate are 10% lower, while the fuel used during takeoff and landing is 17% lower. Intelligence estimates place 18 Scud systems in the Corps sector. The Scuds can be expected to

operate in accordance with current Soviet doctrine. Expect 4 launches every 24 hours. 30% of the Corps AOI in the upper quadrant is not trafficable to wheeled vehicles. Current fuel costs is $.94/gallon. Due to an abundance of excess ammunition left over from Desert Storm, the cost of HE will be 12% lower and the cost of APAM will be 15% lower than original estimates.

The final result from each design group was a system capable of meeting the client's needs with appropriate design specifications and expected performance data. This information would now go to the design engineers for prototyping, possible field testing, production, and fielding.

The goal was to provide the cadets with a real-world systems design experience. Because of the teaching environment, the limited time available, and the requirement to keep the problem unclassified, most of the data for the problem was artificially generated. As the cadet design groups completed a step of the process, a solution was provided to keep the design groups heading in the correct direction. The ideation, creativity, and individualism was maintained through the selection of candidate systems, research and selection of conflicting data, application of weights and utility curves, and the analysis of their results.

Some observations from cadets and instructors that may be important for a real Scud-Busting system are:

- UAVs are too slow to acquire targets.
- ATACMS may be out of range for some targets.
- Satellites are too slow for an acquisition resource.
- Other delivery options should include air-launched missiles.
- JSTARS cost is dependent upon fuel cost.

We think that the methodology demonstrated by the cadets is readily transferable to the actual problem of improving the current system that finds and kills transporter-erector-launchers prior to launch.

Attached are copies from cadet reports of sample work including executive summaries, spreadsheets, graphs, and briefing slides.

APPENDIX A:

CADET EXECUTIVE SUMMARIES

EXECUTIVE SUMMARY

During the Gulf War against Iraqi Forces, the allied forces realized a serious lack in their ability to locate and destroy Scud missiles and their launchers. The Patriot anti-ballistic missile system was the most effective deterrent against Scuds already airborne. However, the Patriot could not ensure satisfactory destruction of Scuds. The Patriot system either failed to completely destroy the warhead, thus allowing severe collateral damage, as occurred with the Scuds aimed at Israel or the Patriot failed, in some instances, to detect the airborne Scud completely, as with the Scud that 'slipped' past the Patriot batteries around Dharhan and destroyed a marine barracks structure, causing severe casualties. The allies also attempted air strikes against the launchers, but these also proved ineffective, as the Iraqis would put dummies or other meaningless vehicles out as targets for Allied warplanes. We could not gather reliable intelligence on targets to locate them or to confirm any destruction. After these attempts to 'beat the Scud', the Allies decided that a system was needed to reliably acquire targets, confirm the location of them and destroy the Scuds 'before' launch. Our design team was called in to design such a system. However, due to lack of funds and support for new research and development, we have been limited to existing assets. We were further guided that this system must also be able to perform anywhere in the world and not just in the Iraqi desert. We have worked diligently over the past four months putting together a system that we find satisfactory to the Allied needs.

Our group has just completed the Preliminary Design Phase of this 'Scudbuster' design. The purpose of this design phase was to not only further narrow down the possible number of alternatives through modeling our systems, but to also find the best alternative through Multi-Attribute Utility analysis. We then stepped back and took a second look though sensitivity analysis to determine if our 'best alternative' would change

if the decision-maker would change his criteria slightly or if the parameters changed slightly. After realizing no change in our selection, we then optimized our alternative by changing the parameters in order to develop our best case scenario. This would allow us to recommend to the decision-maker what parameters he should strive towards to realize the best possible system available. The final step accomplished in this phase was to predict the performance of the Scudbuster in "other-than-desert" environments. This was necessary to determine the usefulness in future confrontations. If it was not compatible, the decision-maker may decide to reject our solution.

We found that, regardless of slight changes in parameters and criteria, Alternative 5 (JSTARS, GUARDRAIL, ATACMS, Current Motor, GPS guidance and ICM munitions) was the best alternative. It should be forwarded to the client for a decision as to whether the system should be fielded or not. We found, however, that our decision is very sensitive to the cost of fuel. In our Prediction of Performance Phase, we found that our system may be eliminated due to the high cost of fuel. Any major upward rise in fuel would cause the elimination of our alternative due to it being too expensive. We recommend that the client research the cost of fuel very seriously. We also recommend that the client research the possible battlefields more closely because the terrain may dictate the amount of fuel used and if too much fuel is used then our system may not be acceptable. Further research of obsolescence factors is also recommended.

EXECUTIVE SUMMARY

The Army tasked our team, from Scud Destroyers, Inc., to develop a system for destroying Scud Missile Launchers. In this, the Preliminary Design Phase, we began with the following four possibly feasible alternatives:

No.	Main Acq.	Confirm Acq.	ASAS	Delivery
1	JSTARS	Guardrail	Yes	ICM
2	JSTARS	UAV,Prop,TV	No	HE
3	JSTARS	Guardrail	No	ICM
4	Guardrail	UAV,Jet,MMW/IR	No	HE

Our purpose in the Preliminary Design Phase was to choose the best from among those four alternatives and to confirm this choice; to determine its optimal parameter settings; and to predict its performance in a realistic environment.

We first determined the best of the four alternative systems by using Multi-Attribute Utility Theory. Our summarized results for our four systems are as follows:

No.	Main Acq.	Confirm Acq.	ASAS	Delivery	Utility
1	JSTARS	Guardrail	Yes	ICM	37.313
2	JSTARS	UAV,Prop,TV	No	HE	---(infeasible)
3	JSTARS	Guardrail	No	ICM	37.472
4	Guardrail	UAV,Jet,MMW/IR	No	HE	68.384

It is clear that the fourth alternative[1] was the best. Our next step was to confirm the soundness of our results through sensitivity analysis. Varying the relative criteria

[1] Note: this alternative is #8, according to the SE402 Preliminary Design Candidate Systems Handout. Alternatives 1,2, and 3 correspond to alternatives 1,2, and 5, respectively, on the handout.

weights did not change our rank order amongst the top two systems (3 and 4) except in one case. #3 became the better alternative if we made the following adjustments to our weights:[2]

Criteria	Old Weight	New Weight
Cost to Search	0.5	0.897065
Cost per Attack	0.5	0.102935

Since this is a substantial change, we can state with confidence that #4 is our best alternative.

Our next task was to optimize this alternative relative to our client's wishes. We accomplished this by varying certain parameters. Our results were as follows:

	Initial System	Optimized System
Utility	68.384	75.308
WarheadWt	350 lb	168.62 lb
# Scuds	35	14
# Shooters	6	12

Our final task was to predict the performance of our system in a Northeast Asian (Korean) environment. We found that our system performed nearly as well in the Korean environment as in our optimized (Middle East) environment: total utility slipped only from 75.308 to 73.309. We also looked at various situations which might cause our system to become obsolete. We found that, observing the development of Scud technology, its pace should be slow enough to allow our system to be usable into the 21st century. Three possible detriments to our system are increased Scud missile

[2] This is actually one adjustment, as the two weights are negatively related: $w_1 + w_2 = 1$.

range, improvements to the survivability of the Scud launcher, and effective counterattacks against our Scud destroyer system. Though our system is only a temporary one, serving for only 10 years until a replacement is found, we feel that the system might become obsolete due to increased Scud missile range.

We recommend that alternative #4, as listed above, be sent forward into detailed design for eventual production and implementation.

EXECUTIVE SUMMARY

War is not a stagnant entity; its nature, tactics, and weapons continually change due to psychological and technological advances. In order to be effective armies need to keep abreast of and responsive to these changes. In response to the events of the Persian Gulf, the United States Army had to change its weapons systems to accommodate a new threat: the SCUD mobile missile launcher. During the Persian Gulf war SCUD missiles threatened the safety of US Armed Forces personnel and the people of Israel, Saudi Arabia, and Kuwait. The SCUD mobile missile launchers have nuclear warhead capability and a maximum range of 70 kilometers, placing most Middle East Cities within its range.[1] Currently the United States Army does not have a weapon system that can effectively destroy the mobile missile launcher. Thus the Army needs an effective and efficient system to destroy SCUD missiles. Based on the Army's need, it is our goal to design an accurate, cost effective, and lethal system of detecting and destroying SCUD mobile missile launchers and their accompanying missiles, before they launch their missile.

In trying to meet our goal we utilized the engineering design process. The Preliminary Design phase is needed to identify the candidate system that best meets the client's needs from the set of defined alternatives.[2] The performance of the best system must not only meet the

clients set of design criteria, but must also better than the other candidate systems. The Preliminary Design phase's four steps (Selection of Alternative, Optimization, Prediction of Performance, and Prediction of Obsolescence) helped the design group determine the best candidate system.

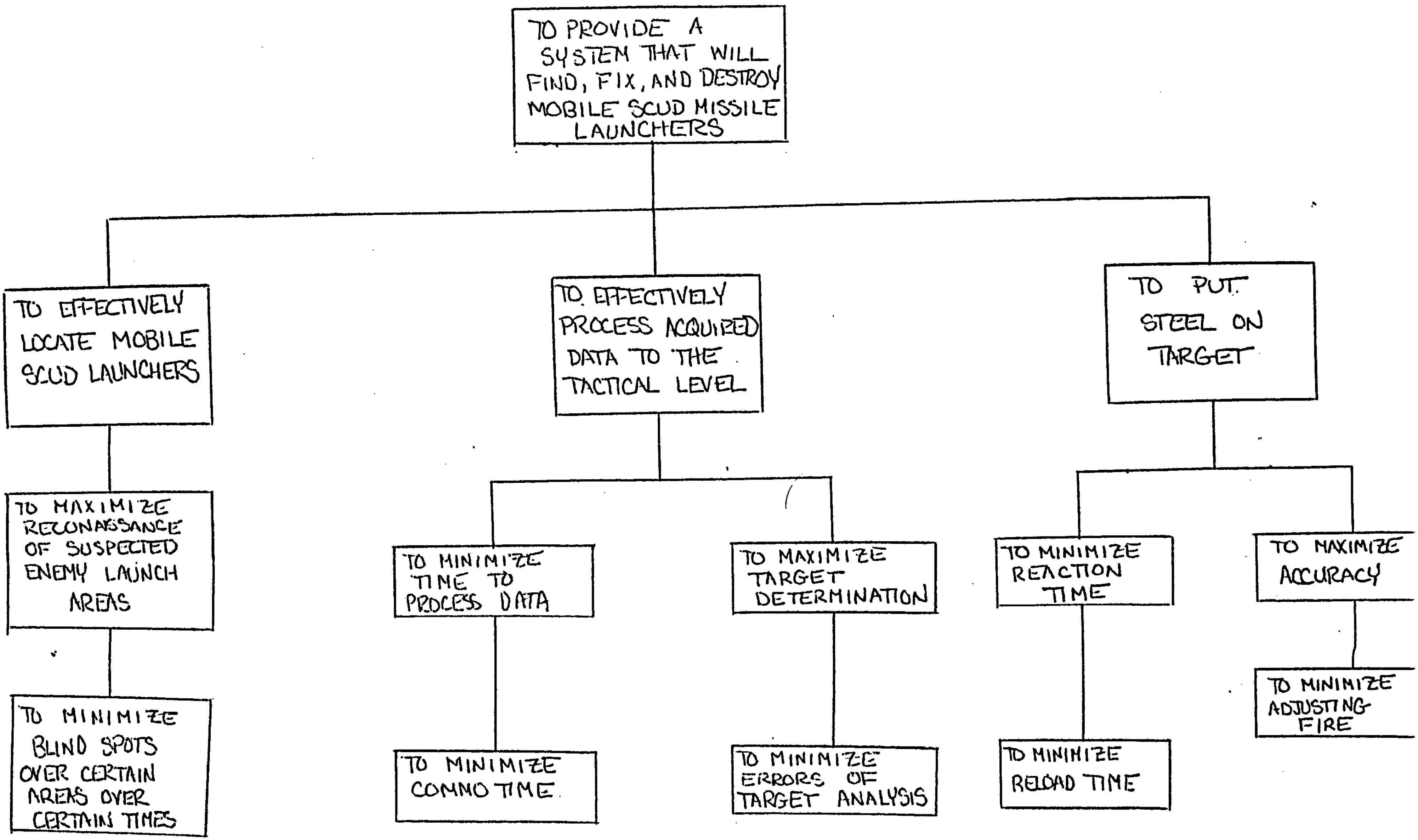
In order to determine the best candidate system we will apply techniques such as, mathematical models of reality, Multi-Attribute Utility theory, use utility curves, and conduct mathematical optimization, to measure the best system in terms of performance. These methods will be applied in succession so as to narrow the field of possible alternatives down to an optimal system.

After much interpretation and analysis from the various Preliminary Design Steps, the design team found that Candidate System C (Initial target location by JSTARS with information sent through the optimal Command and Control network and target confirmation and destruction by a jet-propelled lethal UAV with a MMW/IR seeker with an HE warhead) best met the client's design criteria, was least sensitive to change, and operated effectively in future scenarios, than the four other selections given by the client. Therefore, the design team recommends the client forward Candidate System C, with an optimal utility value of 91.5556 to the Detailed Design Phase for construction and fielding.

APPENDIX B:

CADET GOALS TREE

GOALS TREE


TO PROVIDE A SYSTEM THAT WILL FIND, FIX, AND DESTROY MOBILE SCUD MISSILE LAUNCHERS
TO EFFECTIVELY LOCATE MOBILE SCUD LAUNCHERS
TO EFFECTIVELY PROCESS ACQUIRED DATA TO THE TACTICAL LEVEL
TO PUT STEEL ON TARGET
TO MAXIMIZE RECONASSANCE OF SUSPECTED ENEMY LAUNCH AREAS
TO MINIMIZE BLIND SPOTS OVER CERTAIN AREAS OVER CERTAIN TIMES
TO MINIMIZE TIME TO PROCESS DATA
TO MINIMIZE COMMO TIME
TO MAXIMIZE TARGET DETERMINATION
TO MINIMIZE ERRORS OF TARGET ANALYSIS
TO MINIMIZE REACTION TIME
TO MINIMIZE RELOAD TIME
TO MAXIMIZE ACCURACY
TO MINIMIZE ADJUSTING FIRE

APPENDIX C:

CADET FUNCTIONAL BREAKDOWN AND SYNTHESIS OF SOLUTIONS

ACQUISITION ALTERNATIVES

GUARDRAIL

SATELLITES

ORBITS	IMAGERY
1. 150-250M	INFRARED
2. 400 MI	RADAR

JSTARS

RADAR OPTIONS
1. MTI
2. SAR
3. MTI/SAR

UAV

PROPULSIONS	LOCAT. SYS	SEEKERS
1. FIXED WING JET	GPS-TV	MMW/IR
2. ROTARY WING	GPS-MMW/IR	TV

DELIVERY SYSTEMS

LETHAL UAV (GLTR)

SEEKERS	PROPULSIONS	WARHEADS
1. ARH	1. AIR	1. BLAST
2. GLTR	2. GROUND	2. FRAGMENTATIO
		3. SMART
		4. ANTI-ARMOR

ATACMS

GUIDANCE	WARHEADS	MOTOR
1. INERTIAL PATH	1. 1300LB APAM	1. SRM
2. GPS	2. 350LB	2. SS w/ARCADENE 361
	3. 775LB	
	4. ANTI-ARMOR	

MLRS

WARHEADS
1. ATACMS BLOCK I
2. ATACMS BLOCK II
3. STANDARD MLRS
4. GROUND LAUNCHED TACIT RAINBO

THE ACQUISITION SYSTEMS

SUBSYSTEM 1:	Unmanned Aerial Vehicles		
Subsystems:	Propulsion	Propeller	
		Turbo Jet	
	Location System	Gyro	
		GPS	
	Seeker	Television	
		MMW/IR	
		TOTAL: 8 Combinations	

SUBSYSTEM 2 :	Satellite	
Subsystems:	Orbit	Geosynchronous
		Low Altitude Orbit
	Imagery	IR
		Photographic
		TOTAL: 4 Combinations

SUBSYSTEM 3 :	JSTARS	
Subsystems;	Radar	MTI
		SAR
		Both MTI and SAR
		TOTAL: 3 Combinations

SUBSYSTEM 4: GUARDRAIL Common Sensor
TOTAL: 1 Combination

CONCEPT 1: Ground Station Module with 1 Asset

Subsystems:	UAV	8 Combinations
	Satellite	4 Combinations
	JSTARS	3 Combinations
	GUARDRAIL	1 Combination
	TOTAL	16 Combinations

CONCEPT 2: Ground Station Module with 2 Assets

UAV and Satellite	32 Combinations
UAV and JSTARS	24 Combinations
UAV and GUARDRAIL	8 Combinations
Satellite/JSTARS	12 Combinations
Satellite/GUARDRAIL	4 Combinations
JSTARS/GUARDRAIL	3 Combinations
TOTAL	83 Combinations

CONCEPT 3: Ground Station Module with 3 Assets

UAV/Satellite/JSTARS	96 Combinations
UAV/Satellite/GUARDRAIL	32 Combinations
UAV/JSTARS/GUARDRAIL	24 Combinations
Satellite/JSTARS/GUARDRAIL	12 Combinations
TOTAL	164 Combinations

TOTAL FOR ACQUISITION SYSTEMS: 16+83+164 = 263 Combinations

THE COMMAND AND CONTROL SUBSYSTEM

CONCEPT 1: Quick Fire Channel

Alternatives:

1. GSM located with dedicated Firing Battery. Solution prepared. Notification sent to Corps FSE. Wait for Approval.
2. GSM located with Battalion. Solution prepared and sent to battery. Notification sent to Corps FSE. Wait for Approval.
3. GSM located with Brigade. Solution prepared and sent to Battalion. Notification sent to Corps FSE. Wait for Approval.

CONCEPT 2: Normal Intel/Targeting Channel

Alternatives:

1. GSM located at the Corps FSE. FSE polls ASAS. FSE approves target and sends mission to FA Brigade. Brigade solution sent to Battalion. Battalion solution sent to <u>Battery for action.</u>

TOTAL: 4 Alternatives

Use ASAS? YES, NO 2 Alternatives

Communication network between headquarters (Corps-Bde, Bde-Bn, Bn-Btry):
CTT/MCS or TACFIRE/AFATDS: 2x2x2= 8 Combinations

TOTAL FOR COMMAND AND CONTROL: 4x2x8= 64 Combinations

THE DELIVERY SUBSYSTEM

CONCEPT 1:	Lethal UAV (Ground Launched TACIT RAINBOW)		
Subsystems:	Seeker	MMW/IR	
		Television	
	Propulsion	Propeller	
		Jet	
	Warhead	High Explosive	
		ICM	
		BAT	
		Nuclear	
	TOTAL: 16 Combinations		
CONCEPT 2:	MLRS		
Subsystems:	Warhead	High Explosive	
		ICM	
		BAT	
		Nuclear	
	TOTAL: 4 Combinations		
CONCEPT 3:	ATACMS		
	Guidance	Explicit	
		GPS	
	Warhead	High Explosive	
		ICM	
		BAT	
		Nuclear	
	Motor	Extended	
		Original	
	TOTAL: 16 Combinations		

TOTAL FOR DELIVERY MEANS: 16+4+16 = 36 Combinations

TOTAL COMBINATIONS:

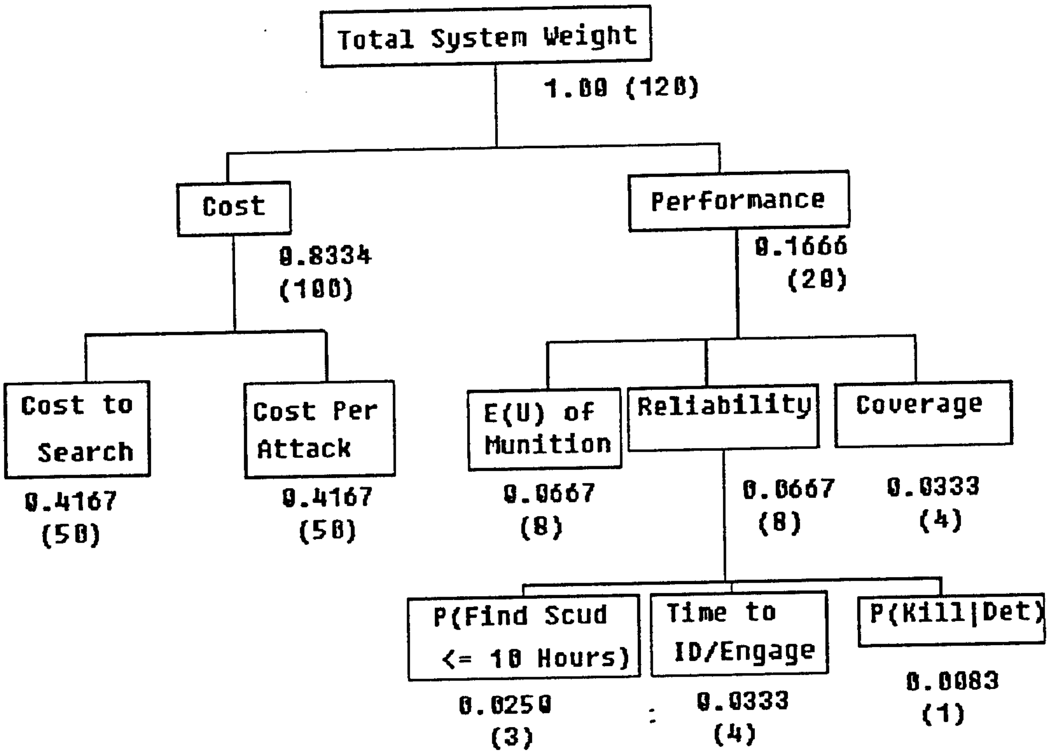
Acquisition Combinations: 16+83+164=263
Command & Control Combinations: 4x2x8=64
Delivery Combinations: 16+4+16=36

TOTAL: 263x64x36=605,952 Combinations

APPENDIX D:

CADET DECISION TREE/
WEIGHTS OF CRITERIA

WEIGHTS



NOTE: Numbers in Parenthesis are Subweights

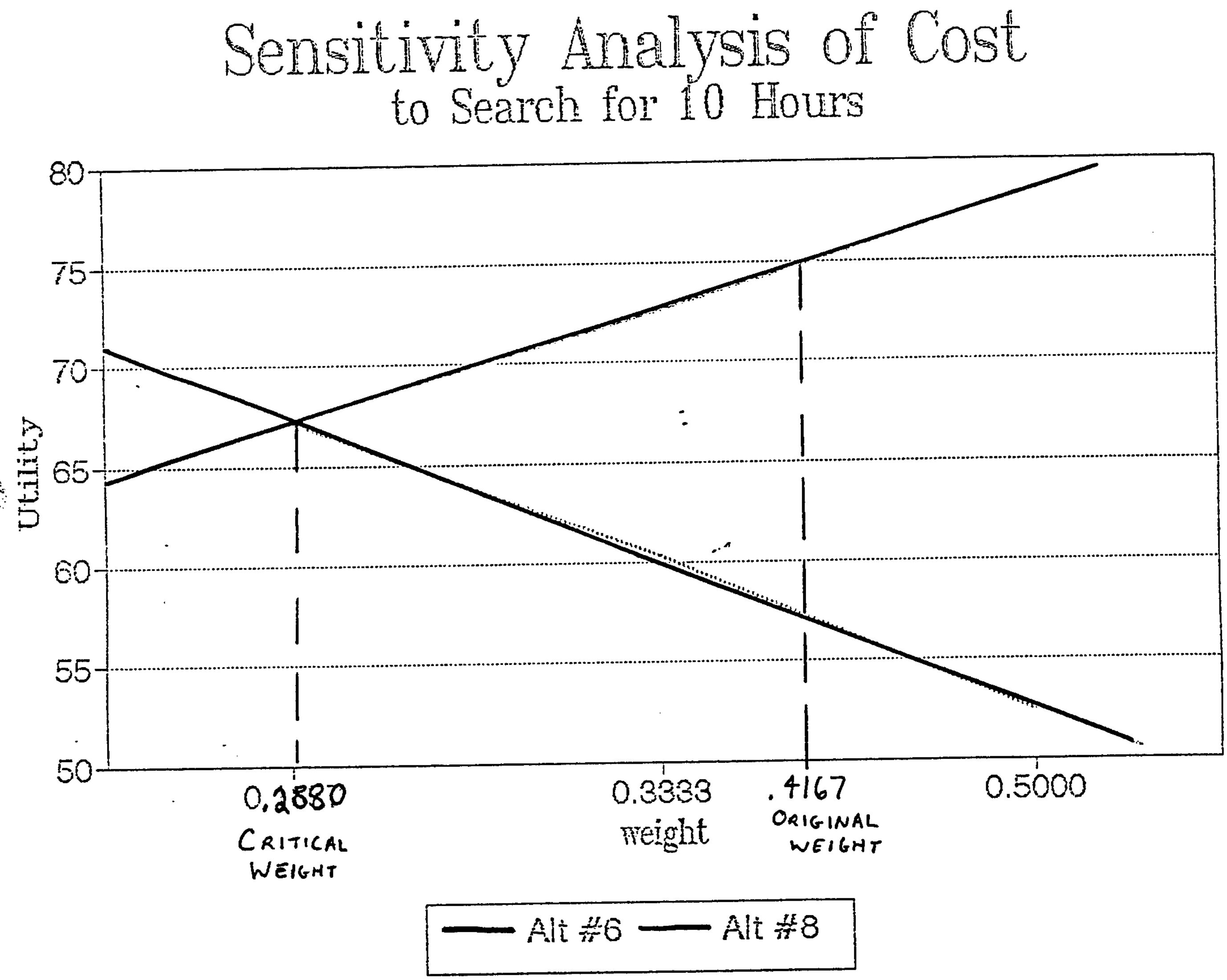
APPENDIX E:

CADET SPREADSHEET

SYSTEM	TIME TO IDENTIFY (sec)	P(FIND SCUD IN 10 HRS)	RANGE OF MUNITIO (km)	P(K/D)	REL.TARG IDENT.	EXP. UTIL MUNITION	PROCOS IN FY95 ($)	SEARCHCO IN 10 HRS ($)	COST PE ATTACK ($)
1	1810.54	0.914417278	350.007	0.61028	0.9932	0.6625	1.1E+08	589895.83	608004
2	6215.54	0.807339081	350.007	0	0.9536	0.6398	8.7E+07	549656.04	465504
3	3610.54	0.914417376	307.976	0.67895	0.99966	0.7734	1.1E+08	589898.11	658404
4	3515.54	0.807341025	307.976	0.56483	0.9892	0.6133	8.7E+07	549656.04	515904
UPPER	900	1	500	1	1	1	7.3E+08	600000	625000
LOWER	3600	0.4	250	0.6	0.6	0.6	1.7E+07	20000	200000
RANGE	2700	0.6	250	0.4	0.4	0.4	7.1E+08	580000	425000
SUBWGH	9	7	7	8	10	10	6	6	8
	0.2143	0.1591	0.1591	0.1860	0.2439	0.2439	0.4286	0.4286	0.6667
WEIGHT			0.67					0.33	
PROPORTION									
	0.24835	0.85736213	0.40003	0.02569	0.983	0.15625	0.13456	0.982579	0.96001
	1	0.678898468	0.40003	0	0.884	0.0995	0.09873	0.9132001	0.62472
	0.91501	0.857362293	0.23191	0.19738	0.99915	0.4335	0.13465	0.982583	1
	0.87983	0.678901708	0.23191	0	0.973	0.03325	0.09853	0.9132001	0.7433
UTILITY	65.1666	85.736213	40.0027	0.41179	96.6289	2.44140625	91.694	8.8032613	14.4933
	0	67.88984679	40.0027	0	78.1456	0.990025	93.9532	23.073402	55.5413
	2.47751	85.73622929	23.1906	8.76916	99.83007	18.792225	91.6885	8.8020674	0
	4.16578	67.8901708	23.1906	0	94.6729	0.11055625	93.9658	23.073402	44.2233
SUBTOTA	13.9643	13.63985207	6.36406	0.07661	23.56802	0.59546494	39.2974	6.36406	9.66222
	0	10.80065744	6.36406	0	19.0599	0.24146951	40.2657	6.36406	37.0275
	0.53089	13.63985466	3.68941	1.63147	24.3488	4.58346951	39.2951	3.6894097	0
	0.89267	10.80070899	3.68941	0	23.09095	0.02695494	40.271	3.6894097	29.4822
SYSTEM	SCORE								
1	57.2564		38.9996					18.256823	
2	52.0392		24.4323					27.606891	
3	46.6299		32.444					14.184876	
4	50.0315		25.7955					24.23607	

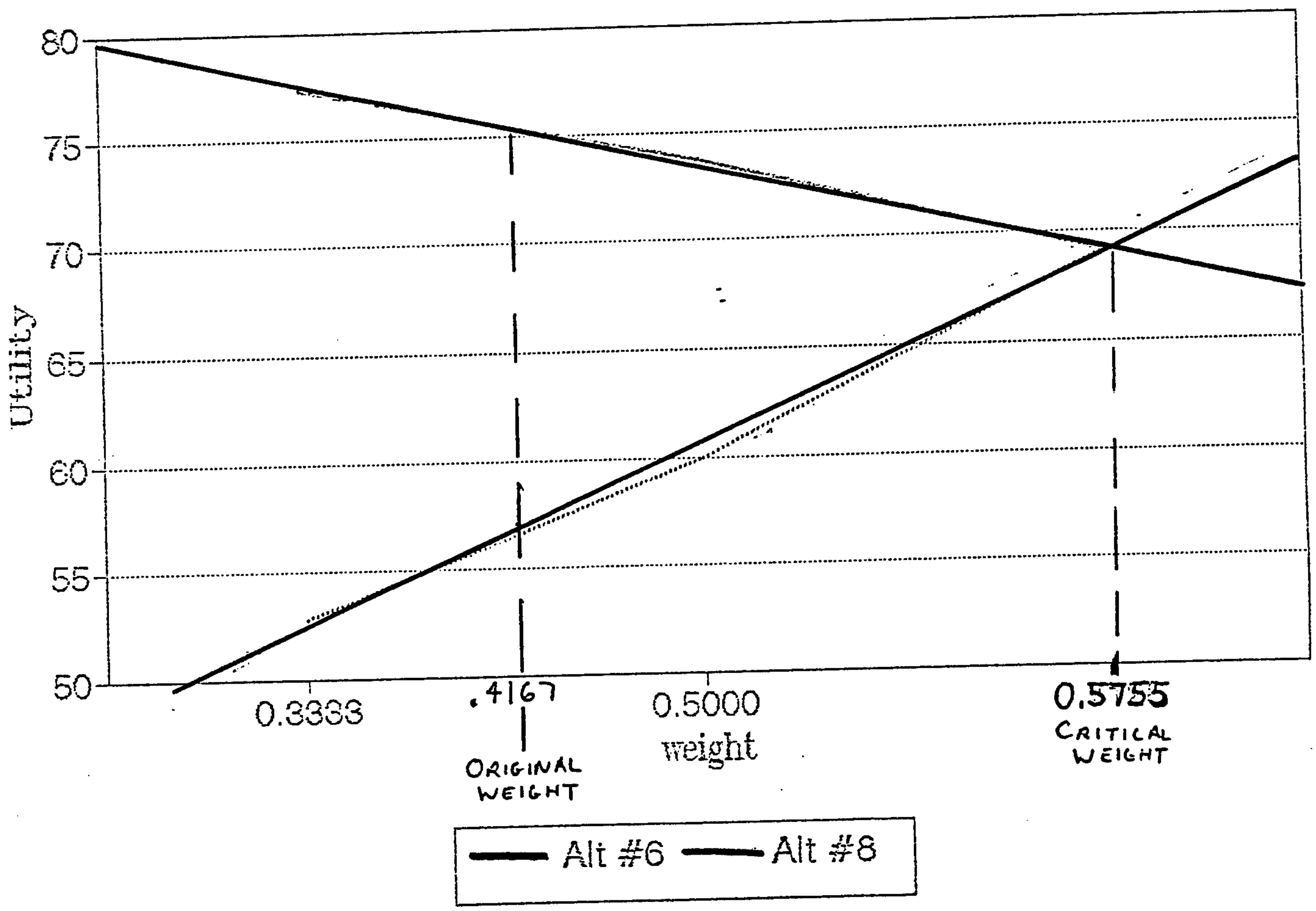
APPENDIX F:

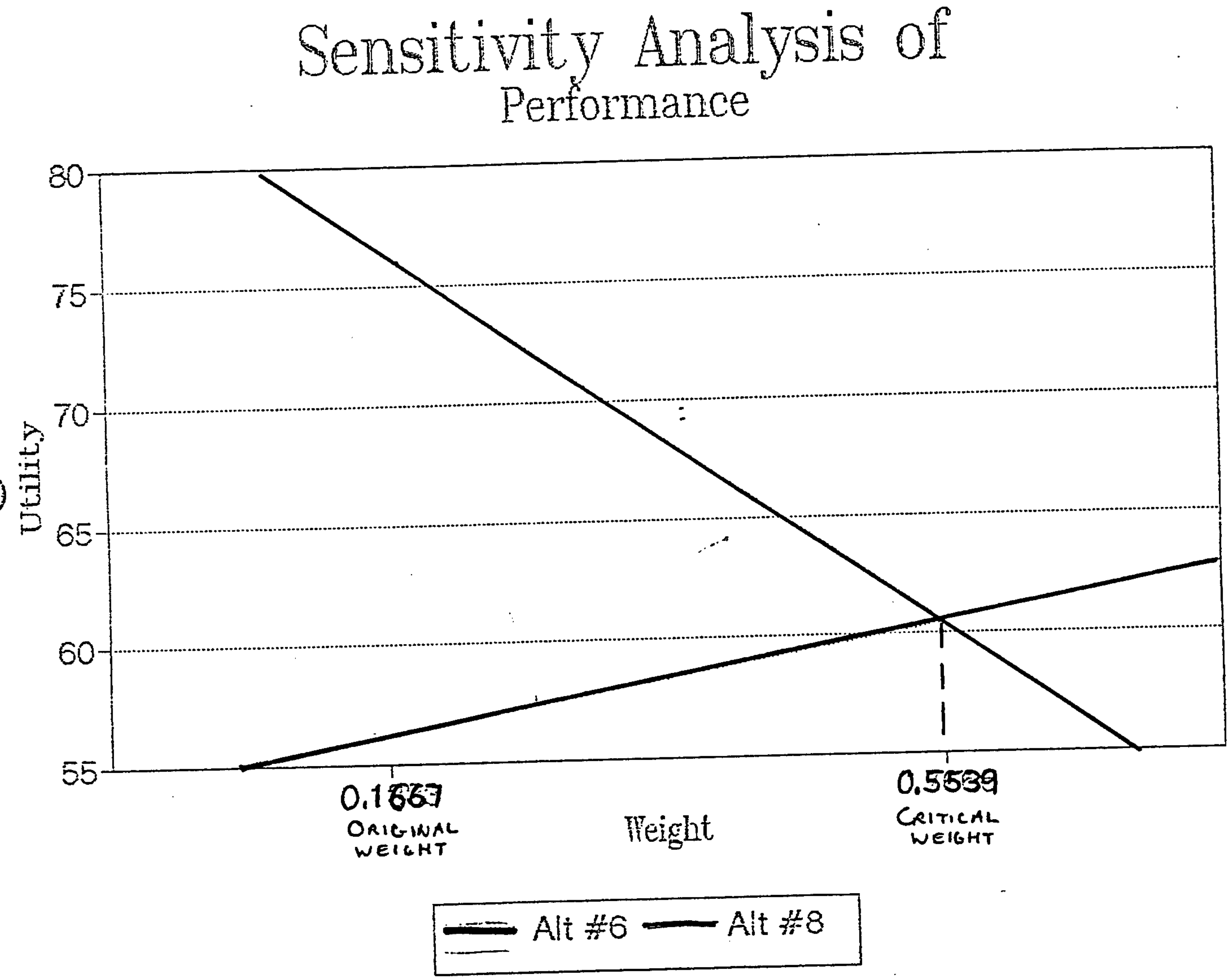
CADET SENSITIVITY GRAPHS



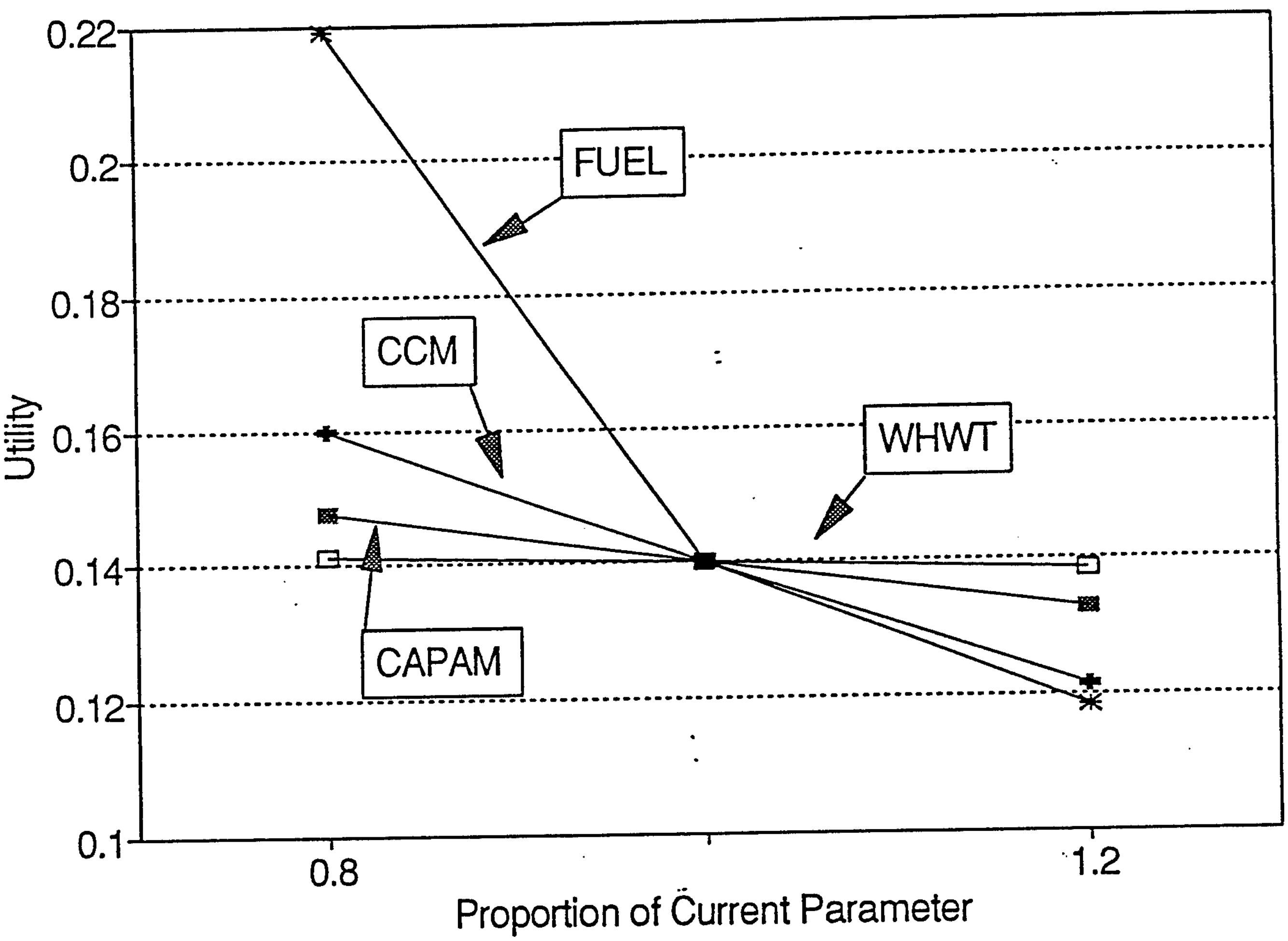
Sensitivity Analysis of Cost
to Search for 10 Hours
80
75
70
65
60
55
50
Utility
0.2880
CRITICAL WEIGHT
0.3333
weight
.4167
ORIGINAL WEIGHT
0.5000
Alt #6
Alt #8

Sensitivity Analysis of Cost
of Munitions



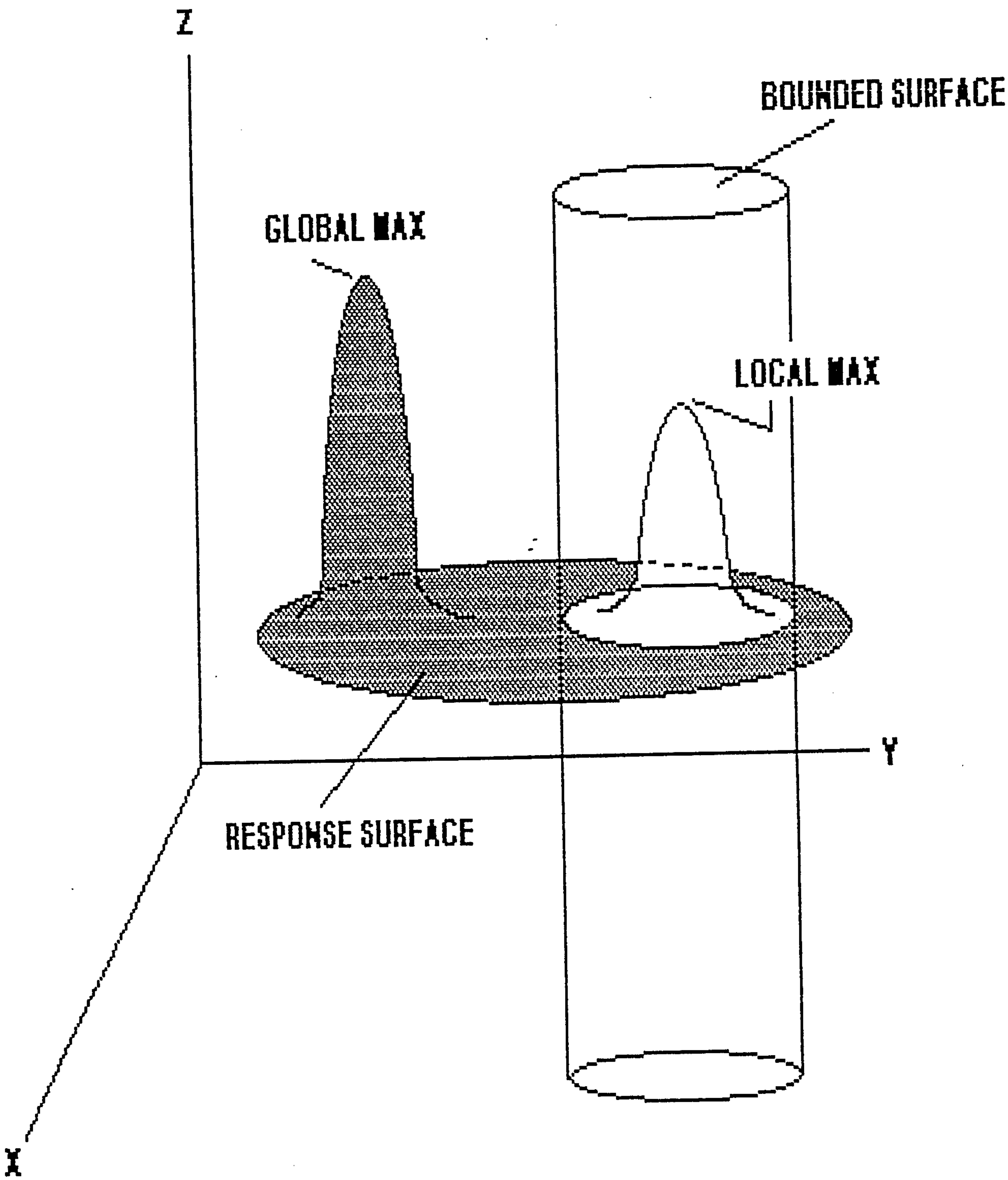

Sensitivity Analysis of
Performance
80
75
70
65
60
55
Utility
0.1667
ORIGINAL WEIGHT
Weight
0.5539
CRITICAL WEIGHT
Alt #6
Alt #8

Alternative 1 Sensitivity Analysis



APPENDIX G:

CADET EXAMPLE OF BOUNDED RESPONSE SURFACE



SOURCE: CALCULUS AND ANALYTIC GEOMETRY
C.H. Edwards, Jr. 1986. p. 777

APPENDIX H:

BRIEFING SLIDES

SYSTEMS DESIGN APPROACH TO PRECISION STRIKE

LTC David W. Hutchison
MAJ Jerry V. Wright

Effective Need

A system is required to find and destroy scud missile launchers prior to them firing their ballistic missiles.

Problem Statement

Develop a system which can detect, identify, and locate enemy targets, analyze and translate target location into firing data, send firing data to attack systems in real time, and ultimately destroy enemy launchers before missile launch.

Implied Tasks

- Operate in any terrain against any enemy.
- System fielded by August 1995.
- Comply with Geneva Conventions.
- Complete mission cycle in real time (10-60 min).

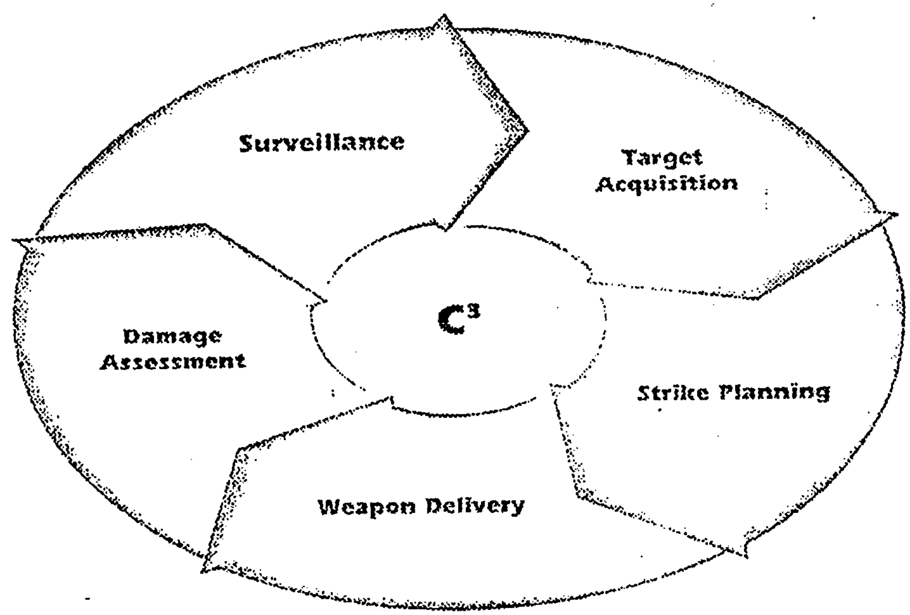
Problem Taxonomy

Target Acquisition

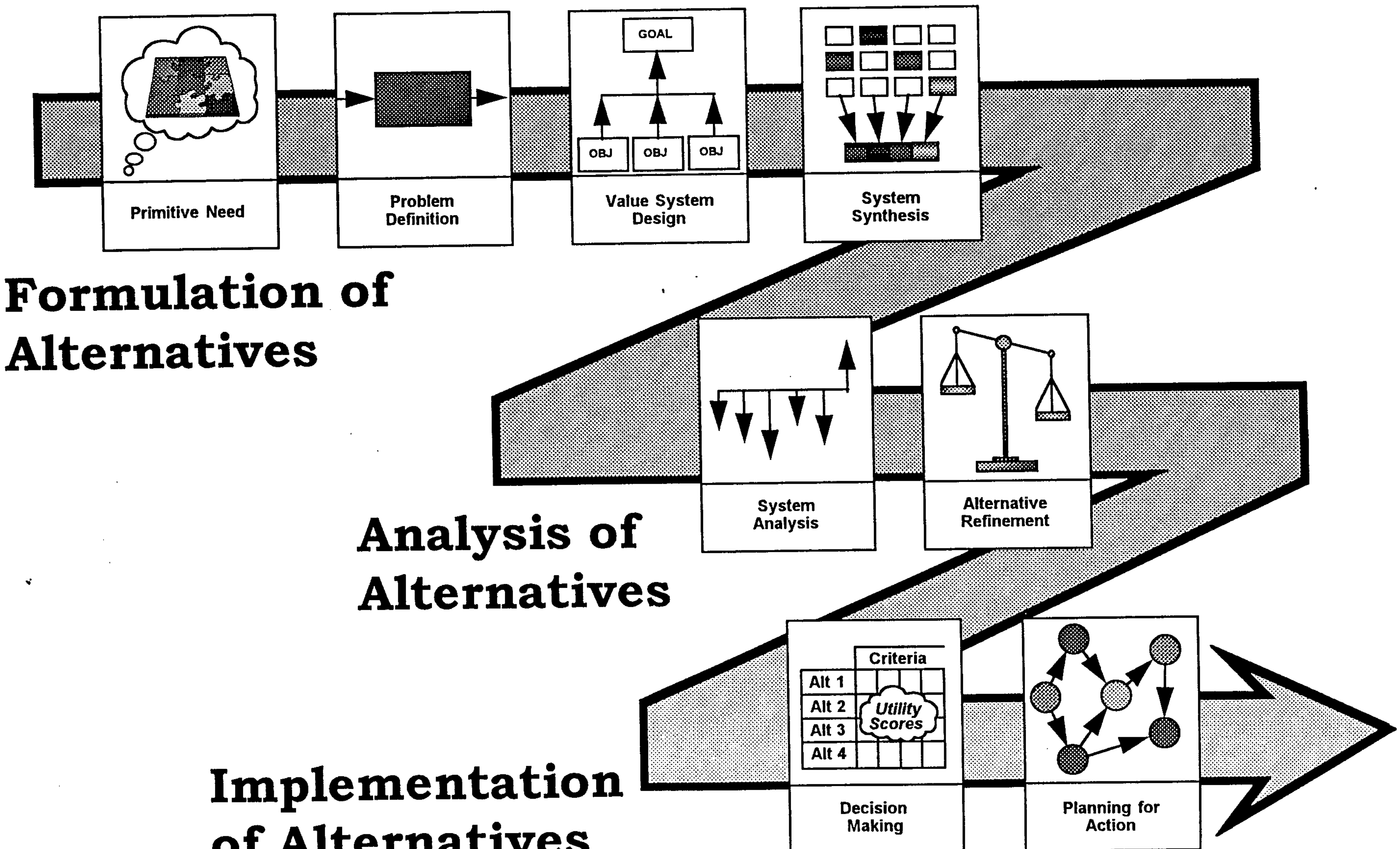
Data Analysis

Command and Control

Weapon Delivery



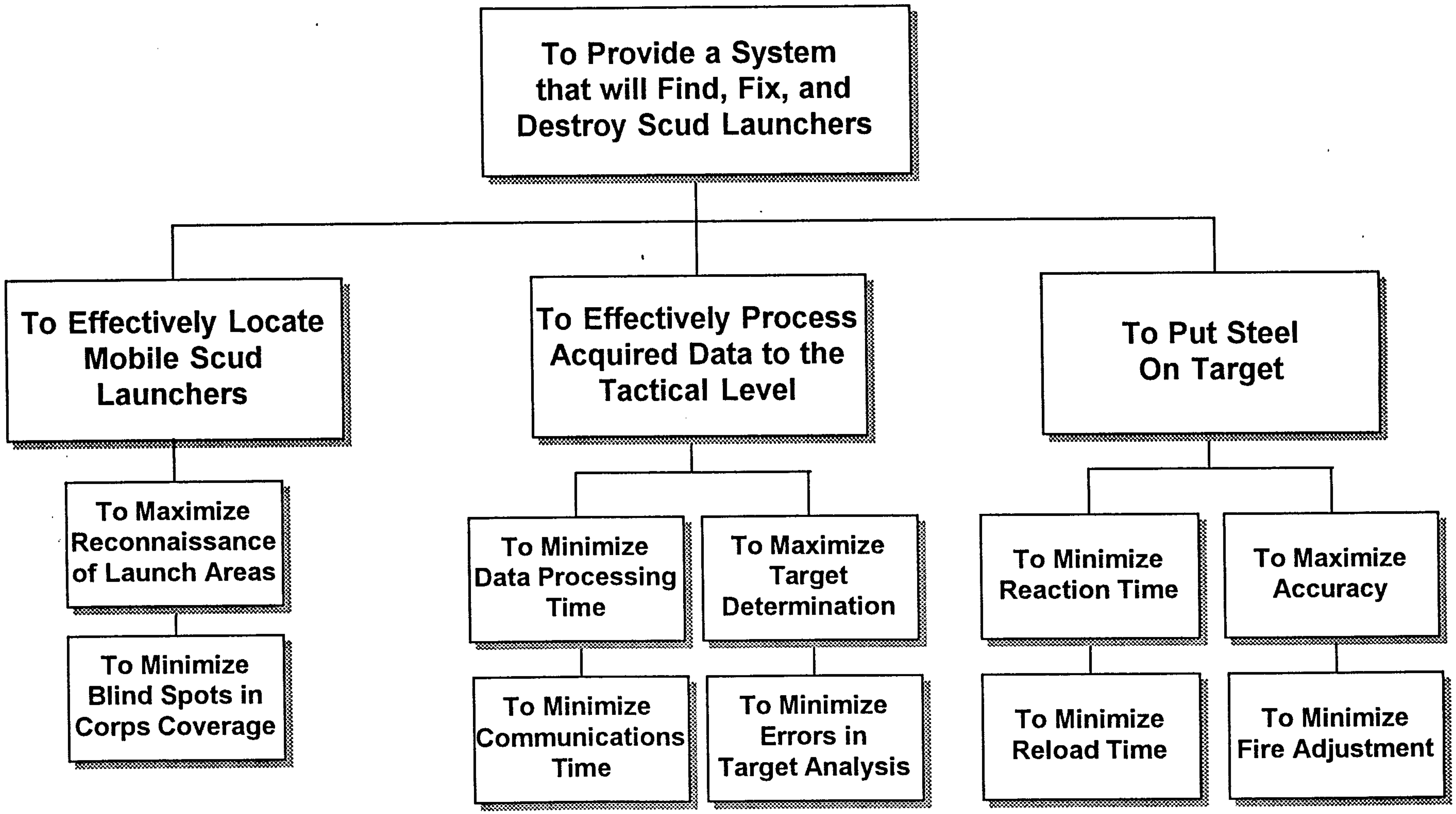
Systems Design Process



Formulation of Alternatives
Problem Definition

NEEDS	EVIDENCE
▪ Improved method to destroy scuds:	▪ Data from a single attack on Tel Aviv:
More effective	28 missiles for 5 scuds
Less costly	$3.56M per scud
Less collateral damage	96 injured by debris
▪ Fielded by 1995	▪ Commander's Guidance
▪ Uses "off-the-shelf" components	▪ Commander's Guidance
▪ Falls within budget constraints	▪ Congressional Guidance
▪ Uses existing doctrine	▪ Commander's Guidance

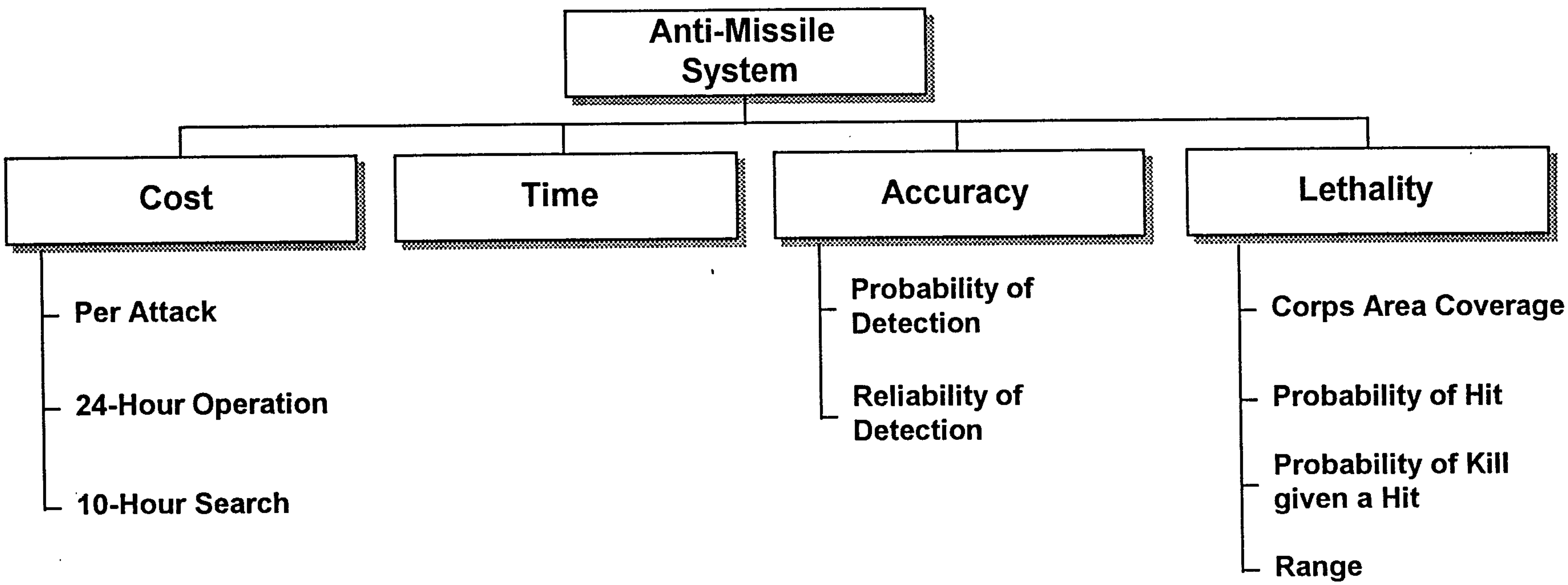
Formulation of Alternatives
Value System Design: Goals Tree



Formulation of Alternatives
Value System Design: Obj Tree

- **Anti-Missile System**
  - **Maximize Effectiveness**
    - Minimize Engagement Time
    - Minimize Employment Time
    - Minimize Detection Time
    - Minimize Enemy Engagement
    - Minimize Maintenance Time
    - Minimize Number of Engageemnts
  - **Minimize Cost**
    - Minimize Total SystemCost
    - Minimize Material Cost
    - Minimize Life Cylcle Cost
  - **Maximize Efficiency**
    - Minimize Training Requirements
    - Maximize Reusability
    - Minimize Transmission Time
    - Minimize Firing Data Time
    - Minimize Flight of Munition

Formulation of Alternatives
Value System Design: Criteria



Formulation of Alternatives
System Synthesis

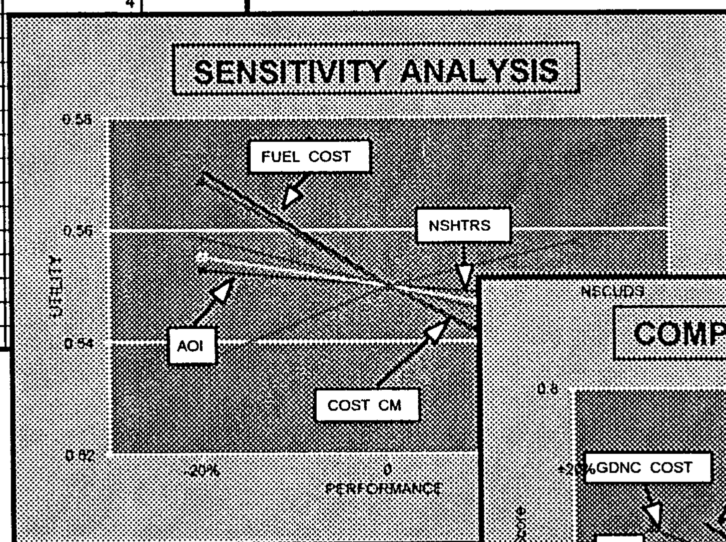
- Acquisition Systems - JSTARS, GUARDRAIL, UAV, SATELLITE
- Data Analysis - GSM, ASAS
- Command & Control - CTT, TACFIRE
- Delivery Systems - MLRS, ATACMS, GLTR

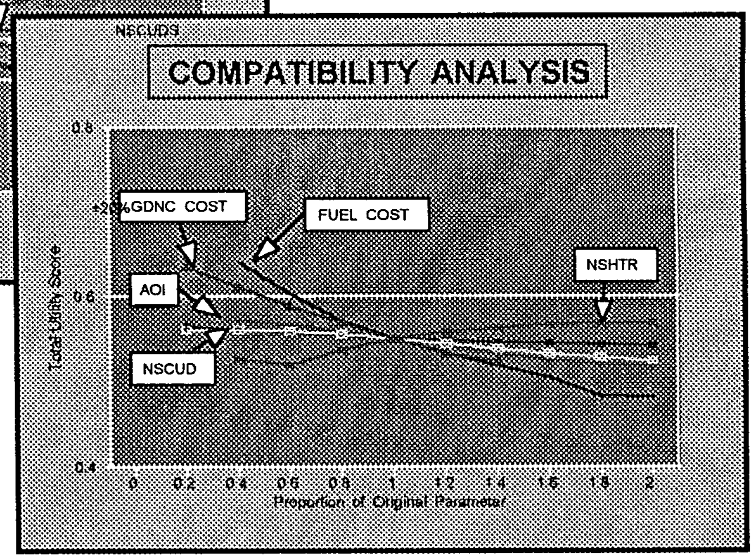
Analysis of Alternatives
Systems Analysis: Modeling

- Time to Engage = f [T(acq), T(xmit), T(proc), TOF]
- Probability of Find = f [AOI Size, NScuds, A/C Speed, Sensor Footprint, Tgt Exposures]
- Range of Munition = f [wweight, lweight]
- Probability of Kill = f [TLE, CEP, BR, EFD]
- Reliability = f [Sensor Type, NSensor, DAnal]
- Expected Utility = f [Sensor Type, P(Find), NSensor]
- Cost to Search = f [A/C Costs, Sensor Costs, Processor Costs]
- Cost to Attack = f [wweight, Cost of Warhead]

Interpretation of Alternatives
Decision Making: Analysis

A	B	C	D	E
PREDICTED PERFORMANCE				
Parameters	ORIGINAL	OPTIMIZED	PREDICTED	
AOI	87000	5000	42000	
WW	350	175	175	
FUELCOST	0.67	0.402	0.94	
NSCUDS	35	14	18	
NSHTRS	6	12	4	
COSTCM	220900	45000		
COSTGD	237600	150000		
COSTHE	264	52.8		
Criteria				
TIME	3273	3273		
P(FIND)	0.9835787	1		
RANGE	349.86187	398.103		
P(KILL)	0.7896878	0.6819175		
E(UTIL)	0.861623	0.973252		
COST(SEARCH	38321.58	23087.87		
COST(ATTACK)	557500	210840		
Total Utility scor	0.5498807	0.8698411		





Cadet Observations

- UAVs are not efficient as acquisition resources.
- Satellites are not responsive as acquisition resources.
- Effectiveness of ATACMS is limited by range.
- Air-delivered weapons may overcome problems in range, timeliness, and collateral damage.
- Destroying launchers on the ground is not the complete solution.